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GROWING CROPS WITHOUT SOIL

For more than a century, physiologists and other plant scientists have studied plant nutrition by growing plants without soil in water culture or sand culture.

In the decade just before the outbreak of World War II, popular interest in soilless culture increased greatly. This interest resulted from research work at the California, Indiana, New Jersey, and Ohio Agricultural Experiment Stations. The first trials were made in greenhouses during the winter with ornamental crops or with vegetables, such as tomatoes and cumcumbers. The new method largely did away with the annual need for obtaining and handling large quantities of soil and compost and for watering, weeding, fertilizing, and soil sterilizing.

During World War II, the United States Army Air Force used the soilless culture method for producing vegetables at certain isolated air bases. At these locations vegetables could not be grown in the available soil or with the natural water supply. After the war, florists and other greenhouse growers adopted the use of soilless culture to some extent.

Soil-borne disease presents one of the most serious problems in soilless culture. The problem is more acute than in soil culture because of the danger from rapid spread of the causal agent in the circulating solution. Because no known materials can be dissolved in the nutrient solution to control diseases while the crop is growing, the beds must be sterilized when not in use. This is done by circulating powerful disinfectants through the pipes, channels, beds, and aggregate material.

Some technical training and considerable experience are necessary for the efficient management of soilless-culture crop production. Successful use of the method requires the same general knowledge of the various phases of plant production necessary for growing plants in soil.

Future commercial development of soilless culture in the United States probably will be confined to production of crops relatively high in value per unit, such as certain ornamentals, out-of-season vegetables, or seedlings for transplanting. Under favorable conditions yields may be expected to equal or surpass yields obtained in soil, but to date the differences have not been outstanding. Soilless culture is also well adapted for

specialized studies in plant nutrition, plant diseases, and plant breeding where growth under exact conditions is desired.

Three general methods of crop production with nutrient solutions, collectively termed "nutriculture," are in use. These are (1) sand culture; (2) water culture, sometimes called hydroponics; and (3) subirrigation culture, also called gravel or cinder culture. Aeroponics is a form of "nutriculture" in which the nutrient solution is sprayed on the plants rather than applied by subirrigation.

SAND CULTURE

In sand culture the soil generally used in beds, benches, or pots is replaced with fine sand, which is watered with a nutrient solution applied to the surface of the sand. The nutrient solution supplies the necessary water and minerals to the growing plants, and the excess solution drains away and is not re-used. Workers at the New Jersey Agricultural Experiment Station have developed the sand culture method. This method is simple and with proper management is capable of producing good crops. Sand culture is useful for experimental studies, but it is not well suited for large-scale production of crops due to higher costs. The nutrient solution is not recirculated, but is drained away.

WATER CULTURE

Water culture is frequently used in experiments on mineral nutrition. The plants are grown with their roots suspended in a nutrient solution contained in shallow tanks, trays, porcelain crocks, or glass jars darkened to prevent growth of algae. They are supported above the solution by wire netting or hardware cloth, which is covered with straw, wood shavings, or rice hulls to exclude light from the solution and to maintain a high humidity around the upper roots. For small containers, hardboard supports (smooth on both sides) are very useful. A 1/2 to 1 inch hole is drilled through the center and the young seedling is inserted through the support. A strip of caulking cord may be used to anchor the plant.

For certain plants aeration of the solution is essential to supply sufficient oxygen to the roots for maximum plant growth. This is done by circulating the solution with a pump that also mixes air with it, or by bubbling air pumped into the solution through perforated pipes. For experimental studies an aquarium pump should be satisfactory. In setting up the aeration device, care should be taken not to splash the nutrient solution on the support. Otherwise, sizable fungal growth may occur and plant damage may result.

The need for aerating the solution and the difficulty of supporting the plants are disadvantages of water culture. Control of the composition of the nutrient solution is also somewhat more exacting than in other methods of soilless culture. For experimental studies chemically pure salts and

and distilled water should be used. Workers at the California Agricultural Experiment Station have contributed most toward developing this method.

SUBIRRIGATION CULTURE

In subirrigation culture, watertight beds or benches are filled with gravel or other suitable inert material, which is irrigated from the bottom of the bed. This method overcomes some of the limitations of the sand-culture and water-culture systems.

Subirrigation culture was developed in 1934 at the New Jersey and Indiana Agricultural Experiment Stations. Subirrigation is accomplished by pumping the nutrient solution from the storage tank or cistern into the bench, the bottom of which slopes slightly from the sides to the middle and also lengthwise. Inverted half-round clay tiles or boards nailed together to form an inverted V are placed end to end lengthwise along the middle of the bench and serve as a channel for the solution. When the solution has nearly filled the bench, the pump is stopped either manually or by an electric time switch and the solution drains back to the tank by gravity. This type of installation, known as the direct-feed system, is useful in greenhouses, propagation units, or other small systems. In the newer benches built for subirrigation, a solution channel is formed by making a longitudinal depression along the lowest part of the bench floor. The channel thus formed is covered with bricks or slabs of concrete provided with drainage holes at the sides. To facilitate rapid drainage, these holes are covered with coarse gravel.

For larger installations the gravity-feed system is more economical to use. The beds, or benches, are divided into three or four sections, each on a higher elevation and slightly longer than the one following it. Two tanks of solution are used in this system. A larger tank is located at the lower end of the beds and is below ground. It is connected by a flume with a somewhat smaller tank about the level of the highest beds. The smaller tank should have a capacity approximating one-half the volume of the first sections of all the beds. This tank is filled from the larger or sump tank before an irrigation is made. The nutrient solution flows into the first bed sections by gravity and then successively through the other sections, finally emptying into the sump tank. By this means only the solution for irrigating the first sections of the beds has to be pumped. Gravity flow irrigates the rest of the sections. After one or more irrigations have been made, the solution in the sump tank is analyzed, reinforced with the necessary nutrients, made to volume, and pumped into the elevated tank in preparation for the next irrigation. This system was used in the 1940's by the United States Army in the operation of soilless culture gardens at Ascension Island, Atkinson Field in British Guiana, Iwo Jima, and in Japan.

A modification of tier construction known as the open-flume system has been developed in Florida. All the solution is carried to and from the beds by a flume, so that no piping or valves are necessary except at the pump. The nutrient solution is stored in a tank above ground, with a small

sump tank for the pump, or in a cistern below ground.

Benches or beds intended for subirrigation are usually built of suitably reinforced concrete. They should always be coated on the inside with non-toxic pertroleum asphalt applied hot, as an emulsion, or cut back in a volatile solvent. The asphalt serves to waterproof the beds and to protect them from the salt action of the slightly acidic nutrient solution. Ground beds of asphalt macadam may be constructed by mixing hot asphalt with sand and molding the bed into shape while hot. This type of bed was used in the Ascension Island installation.

Prefabricated bituminous surfacing (PBS) consisting of burlap saturated with asphalt was successfully used for constructing subirrigated beds in the Iwo Jima garden. This material has the advantage of being tough, flexible, waterproof, and easily laid. If it becomes generally available, PBS should be very satisfactory for waterproofing existing wooden benches for subirrigation.

NATURALLY OCCURRING MATERIALS

Several naturally occurring mineral materials, or aggregates, have been used in the soilless culture of a number of plants. Lava cinder was screened and used in the beds on Ascension Island and Iwo Jima. Gravel washed free of sand and clay has been widely used in the United States. Sintered shale (Haydite), a commercial product used in making low-density concrete, is porous, is light in weight, and has a higher water-holding capacity than gravel. Calcareous aggregates (coral limestone) have produced satisfactory crops experimentally after being pretreated with phosphate solutions to stabilize the reaction of the solution. Expanded vermiculite, a micaceous silicate used industrially as an insulating material, was useful as an aggregate in soilless culture tests at the U. S. Plant Industry Station. Haydite and vermiculite contain calcium and potassium and tend to absorb phosphates, which are available to the plants growing in them. Consequently, the acidity and nutrient balance of solutions used with Haydite and vermiculite do not fluctuate as rapidly as when the aggregate is gravel. Perlite may also be used. The particle size of the aggregates should lie between one-sixteenth inch and one-half inch in diameter. The frequency of irrigation is determined in part by the water-retaining capacity of the beds and by the particle size and porosity of the aggregate, but principally by the size and type of plant grown and the environmental conditions.

SYNTHETIC MATERIALS

Lightweight materials, such as foam plastics and other synthetic substances, (plastic beads, polystyrene foam, and urea formaldehyde foam) may be used as a growth medium in soilless culture.

COMPOSITION OF NUTRIENT SOLUTION

The nutrient solution supplies water and oxygen as well as mineral elements to the plant roots. Much effort has been expended in attempts to determine the best combination of nutrients for various plants. While many combinations have been proposed, it is now generally recognized that rather wide limits of solution composition are capable of producing equally good growth of many plants. Environmental factors, such as temperature, light intensity, and carbon dioxide level, and the plant part desired (leaf, root, fruit, or flower) are also determining factors in solution composition for optimum growth. The total volume of the solution in relation to the number of plants, the particle size of the aggregate, the frequency of irrigation and replenishment of absorbed nutrients, and the initial PH and composition of the solution are important factors in governing growth. With small installations the nutrient solution can be replaced at frequent intervals with a solution prepared by diluting ready-mixed soluble fertilizer concentrates according to the manufacturer's directions. These materials are generally available at garden supply houses. In larger systems it is more economical to test the solution and to replenish the elements as they are absorbed. For experimental studies, a satisfactory regime is to add nutrient solution on Monday, Wednesday, and Friday (or every other day) and add distilled water on the remaining days. The solution should be renewed at least once a week.

NUTRIENT SOLUTION

Composition of the nutrient solution best adapted for use in soilless culture depends to some extent upon the type and particle size of the medium that is used in the beds, composition of the water, kind of plant grown, age of the plant, location, and time of the year. Two solutions that have been used have the following composition in pounds and ounces per 1,000 gallons of water:

	Solution 1		Solution 2	
Salt	Pounds	Ounces	Pounds	Ounces
Potassium nitrate	9	3	5	13
Ammonium sulfate	1	3	1	0
Monocalcium phosphate	2	10	2	8
Magnesium sulfate	4	6	4	8
Calcium sulfate	6	6	5	0

In addition, small amounts of minor or trace elements are required. The ones usually added in terms of grams per 1,000 gallons of water follow:

Salt	Grams
Ferrous sulfate	38
Maganese sulfate	12
Boric acid	10
Zinc sulfate	2.5
Copper sulfate	0.9

When noncalcareous aggregates are used, the reaction of the solution should be adjusted to about pH 6.8 with sulfuric acid or sodium hydroxide solution, depending on the initial pH.

In arid regions of the world, soilless culture is especially promising. Considerable research is now being conducted in Israel and other locations on this method of growing plants.

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